Inclusion of Renewable Energy Topics in the Design of Experiments Course for Industrial and Systems Engineering Students

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Abstract

As a branch of engineering, industrial and systems engineering (ISE) deals with the design and management of complex processes or systems. It is an interdisciplinary field that involves the analysis and optimization of the way of integrating various resources such as people, finance, information, equipment, energy, and materials. Statistics show that ISE graduates are popular in job markets and many of them end up in the high-end consulting and management positions. The success of the ISE graduates in job markets is due largely to their wide and rapidly evolving knowledge base. Design of experiments (DOE) is a general method with broad applications to identify the influences of various variations on the systems or processes. It is traditionally a fundamental course offered to students in various ISE programs across the American universities. This paper presents a recent effort at a research university in the U.S. to integrate renewable energy topics into the traditional DOE course to help ISE students update their knowledge base and foster environmental responsibility and sustainability awareness in their future careers. A new topic related to the manufacturing of a specific form of renewable energy, cellulosic biofuel, has been integrated into an eight-week course project session. The course-end evaluation and survey have shown a significant increase of interest in energy security and sustainability among students in the course. The students have been theoretically and practically more prepared with the DOE tools for the evolving job market of green energy manufacturing.

1. Introduction

This paper presents a recent effort at a research university in the United States to integrate renewable energy topics into the traditional design of experiments (DOE) course. The objective of this activity is to help industrial and systems engineering (ISE) students update their knowledge base and foster environmental responsibility and sustainability awareness in their future careers in various industrial sectors.

As a branch of engineering, ISE deals with the optimization of complex processes or systems. It involves the development, improvement, implementation, and evaluation of integrated systems of people, finance, knowledge, information, equipment, energy, and materials. According to the Occupational Outlook Handbook of the U.S. Department of Labor [1], the main duties of industrial and systems engineers involve finding effective ways to use workers, machines, materials, information, and energy to make a product or provide a service. In various different projects, industrial and systems engineers focus on how to get the work done most efficiently, balancing many factors. The versatility allows industrial and systems engineers to engage in activities that are valuable to a variety of businesses, governments, and nonprofits. Many industrial and systems engineers move into management positions because their work is closely related to the work as managers [2].

Becoming an industrial and systems engineer generally requires a Bachelor's degree in an ISE program, which is offered by many universities and accredited by the Accreditation Board for

Engineering and Technology (ABET). DOE is a typical course taught to undergraduate and graduate students in the ISE programs of many universities to enhance their problem-solving skills using mathematical methods and models [3-9]. DOE deals with purposely changing input variables of a process or system in order to identify reasons for changes observed in the output variables [10]. As one of the main deliverables of DOE, an empirical model can be formulated and used to guide the decision making processes leading to optimal performance of the system. DOE methods have found broad application in many disciplines. It is especially useful for new problems in science and engineering that require careful observation and intensive experiments to elucidate knowledge due to the lack of profound understanding of the system under study.

The training of ISE students involves enriching their knowledge of the fastest growing industries. One of such industries is related to the renewable energy technologies. Trials on the inclusion of renewable energy technologies in the DOE course have been reported in the literature. Examples include [11-15]. However, the majority of the literature focuses on solar and wind energy and largely ignores other types of renewable energy technologies. Since ISE graduates must be prepared to work with other professionals to serve as a bridge between the technical and business sides of an organization, the inclusion of other types of renewable energy technologies will benefit ISE students in their future careers.

Conventional liquid transportation fuels are derived from petroleum and account for 70% of total petroleum consumption [16]. About half of the petroleum consumed in the U.S. is imported [17]. Also, the use of petroleum-based fuels contributes to the accumulation of greenhouse gases (GHG) in the atmosphere. Finite reserves, non-uniform distribution, volatile prices, and GHG emissions of petroleum make it extremely important to develop domestic sustainable sources for liquid transportation fuels. One such source is cellulosic biomass (fibrous, woody, and generally inedible portions of plant matters). The total annual capacity of large-scale cellulosic biofuel plants currently in operation or being built in the U.S. is less than 0.5 billion gallons [18], which lags far behind the expectation. In order to meet the U.S. government's mandate of 16 billion gallons of cellulosic biofuels annually by 2022 [18], many large-scale plants will have to be built.

Therefore, the authors make a trial on the inclusion of the cellulosic biofuel topic in the DOE course to broaden the knowledge of ISE students in the manufacturing of renewable energy. It is also our hope that the environmental and sustainability awareness will be fostered or enhanced among the students, which can further benefit their future careers in various industrial sectors.

2. Course Project Description

Design and Analysis of Experiments in Engineering was a four credit-hour course (including three credit hours for class teaching and one credit hour for the lab session) offered to both undergraduate and graduate students in the ISE program at the target research university in the United States. The course used a required text book, Design and Analysis of Experiments, 8th Edition, by Douglas C. Montgomery (ISBN 978-1-1181-4692-7) published by John Wiley in 2012. The objectives of the course were: 1) helping students develop the ability to translate industrial problems into an appropriate experimental design problem, 2) helping students develop the ability to appropriately analyze experimental data and communicate the results, and 3) introducing the techniques for variance reduction through robust parameter design. The lectures covered simple comparative experiments, single factor experiments, randomized blocks, Latin squares and related designs, factorial design, regression modeling, response surface method, as well as other approaches to optimization, robust design, random factors, and nested/split-plot designs. The use of Minitab software in solving chapter-end exercise problems and analyzing project data was taught during the mandatory lab session.

The course project was assigned after the mid-term exam. The background information of the project was briefly introduced in class. A project report, which accounted for 20% of the total semester grade, was required to be submitted at the end of the semester. There were a total of 33 students registered in the class. Students were asked to formulate teams voluntarily when conducting the project. Each team consisted of two students except for one team, which consisted of three students. Two project topics were offered and each team could only choose one topic based on their interest. One project topic was related to cellulosic biofuel manufacturing, and the other was related to traditional manufacturing. The requirements and workload for completing each project were the same, and each team has a full freedom to pick up either topic to work on. Among the total of 16 teams, finally, 13 teams selected the biofuel manufacturing topic and only three teams worked on the traditional manufacturing topic. This result clearly illustrates the significant interests from students in the renewable energy topic.

The biofuel project is described as follows. The cellulosic biofuel is an important form of renewable energy. It plays a crucial role in helping reducing GHG emissions and controlling the greenhouse effect. As shown in Figure 1, one trial design of the manufacturing procedure of the cellulosic biofuel involves the following five steps: size reduction, pelleting, pretreatment, hydrolysis and fermentation. The size reduction process converts raw cellulosic biomass (e.g., corn stover) into small particles. The pelleting process transforms the particles into high-density pellets that can be transported and handled more efficiently. Pretreatment breaks the lignin seal and disrupts the crystalline structure of cellulose, increasing its surface area and making it more accessible to enzymes in hydrolysis. Hydrolysis breaks down cellulose into fermentable sugars (e.g., glucose) for biofuel manufacturing through fermentation. The fermentable sugars are fermented into biofuel (e.g., ethanol) in the fermentation process.

Figure 1. Cellulosic Biofuel Manufacturing Processes

Each process may influence the overall biofuel manufacturing performance. Since this manufacturing technology is still not so mature, there are still a lot of parameters (or factors) to be determined for each process in order to obtain the best manufacturing performance. Two leading performance measures of the cellulosic biofuel manufacturing system are production rate (or throughput) and energy consumption. This course project is only concerned with energy consumption. More specifically, we plan to analyze the provided experimental data of the first two steps, size reduction and pelleting, to see what factors have the main effects on these two procedures regarding energy consumption, and then recommend optimal settings of input variables for these two processes.

The project data given to students were provided by our research collaborator based on experimental results. For the process of size reduction, experiments were conducted using poplar wood chips as the biomass. The sieve size and the moisture level were the two main factors considered in the experiments (see Figure 2). Three different levels of each factor were examined. Two replicates of the experiments for each combination of different levels of the two factors were conducted. For the process of pelleting, four types of biomass were studied, i.e., big bluestem, corn stover, sorghum stalk, and wheat straw. Three other factors, the biomass size, the pelleting power, and the pelleting pressure are considered. The experimental data given to students involved two different biomass sizes for each type with three different settings of power and three different settings of pressure. Two replicates of the experiment for each combination of different levels of the three factors were conducted. The detailed results of the experiments were provided in an Excel file.

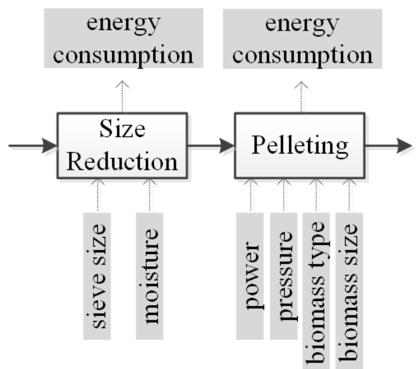

Figure 2. Experimental Design Variables (Inputs and Outputs) for the Size Reduction and Pelleting Processes

The students were asked to analyze the experimental data and write a report with the conclusions and recommendations for the setting of input variables for the two processes.

3. Course Project Grading and Analysis

Most of the teams have completed all the required data analysis tasks using knowledge learned from the class and composed their report including the following parts. For more detailed information, we refer the reader to an example report on the cellulosic biofuel project by Sun et al [19].

- A short description of the problem (2 points).
- An explanation of the critical steps in the analysis of the experimental data, including but not limited to: experiment results, regression model, model adequacy analysis, contour and/or surface plots, as well as relevant Minitab outputs (10 points).
- Recommended settings for factors and the associated predicted response, and 95% confidence intervals for the outputs (4 points).
- Justification for the recommendations based on the analysis (2 points).
- Recommended next steps (2 points).

Since the course project score accounted for 20% of the total final grade, all the reports for these two topics were carefully reviewed by the lecturer and graded on a scale of 0 to 20. The grades are listed in Table 1. A boxplot is also plotted in Figure 3 to compare the grades of the teams selecting the two topics. As mentioned in Section 2, students formulated the teams freely, and therefore each team may consists of a mix of graduate and undergraduate students when conducting the project. The instructor did not differentiate graduate and undergraduate students in grading and treated all the teams equally.

Table 1. Course Project Grades

Team Number	Number of Students	Grade	Topic
1	2	16	Biofuel
2	2	17	Biofuel
3	2	20	Biofuel
4	2	20	Traditional
5	2	12	Biofuel
6	2	16	Traditional
7	2	18	Biofuel
8	2	17	Biofuel
9	2	16	Biofuel
10	2	17	Biofuel
11	2	15	Biofuel
12	2	15	Biofuel
13	2	9	Biofuel
14	2	14	Traditional
15	2	15	Biofuel
16	3	17	Biofuel

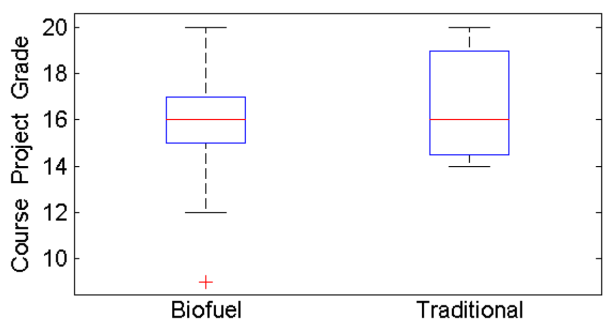

Figure 3. Boxplot of the Course Project Grades

It can be seen from Table 1 that 13 out of the 16 teams have voluntarily selected the biofuel manufacturing project, which indicates that this topic interests them more than the traditional manufacturing topic. The boxplot shows the grades of the teams selecting the biofuel project are more widely spread. The reason for this is that the traditional topic group includes a relatively small sample (only three grades).

A hypothesis test is conducted using the *F*-test to test if the two groups (biofuel grades and traditional grades) are distributed with the same variance. The *P*-value is 0.595 for the significance level of 0.05, which indicates there is no significant evidence to reject the null hypothesis that the biofuel grades and the traditional grades have the same variance. Another hypothesis test is then conducted using the *t*-test to test if the two samples have the same mean. The *P*-value is 0.651 for the significance level of 0.05, which indicates there is no significant evidence to reject the null hypothesis that the biofuel grades and the pharmaceutical grades have the same mean.

4. Course-End Survey Analysis

At the end of the course, the students were surveyed regarding the inclusion of renewable energy topic in the course project. Seven multiple choice questions (each with only one correct answer) and one open-ended question were provided in a questionnaire for each of the 33 students. Finally 30 effective questionnaires have been collected and analyzed. The responses to the multiple choice questions are shown in Figures 4 through 10. In these figures, the number associated to each bar represents the number of students responding to that specific choice.

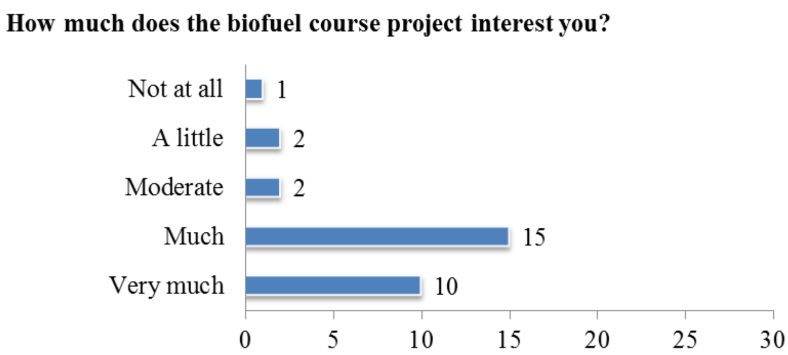

Figure 4. Survey Question 1 and Responses

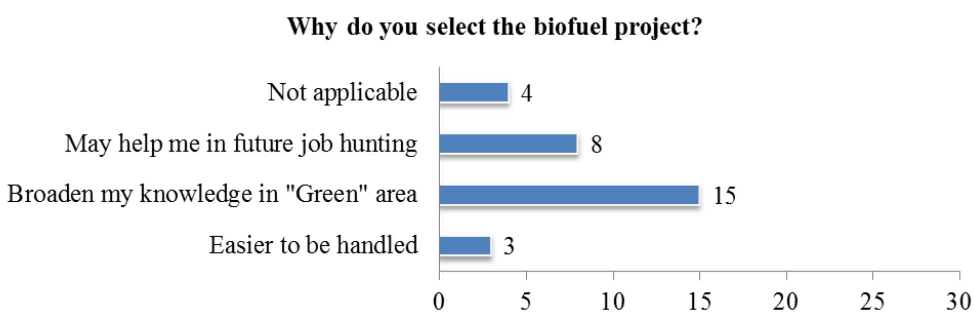

Figure 5. Survey Question 2 and Responses ("Not applicable" means the students selected the other topic)

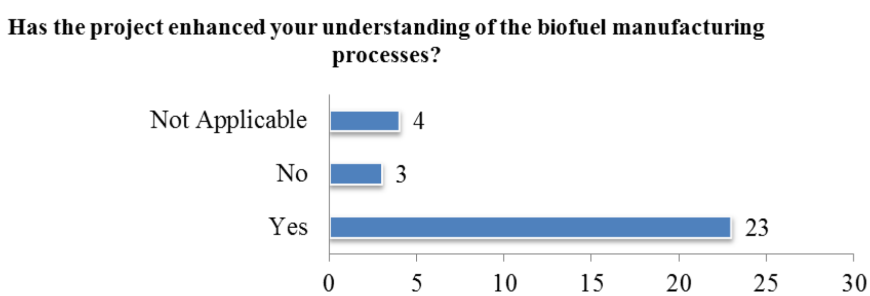

Figure 6. Survey Question 3 and Responses ("Not applicable" means the students selected the other topic)

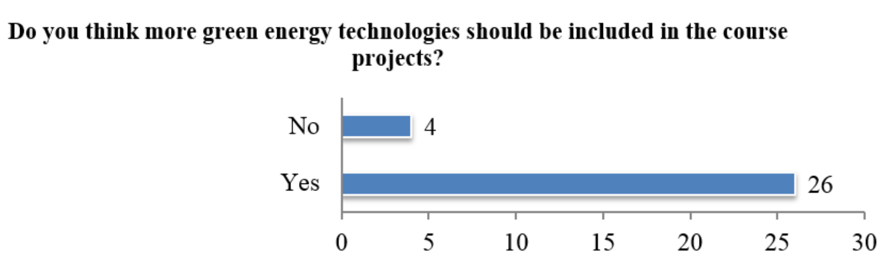

Figure 7. Survey Question 4 and Responses

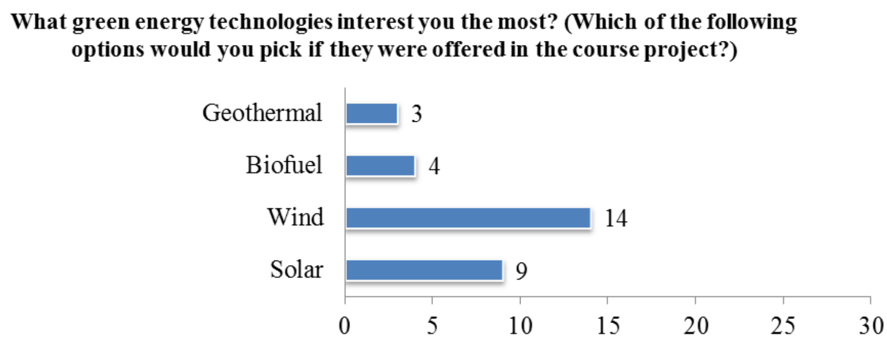

Figure 8. Survey Question 5 and Responses

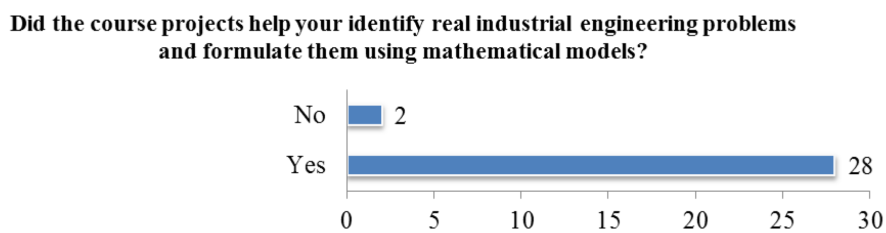

Figure 9. Survey Question 6 and Responses

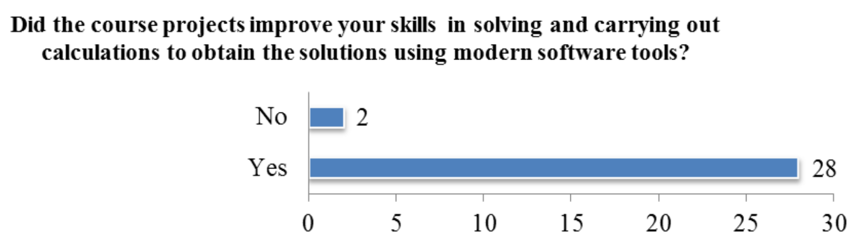

Figure 10. Survey Question 7 and Responses

Figure 4 indicates that 25 out of the 30 students show interests ("much" and "very much") in the biofuel project. Figure 5 shows that the main reasons for choosing the biofuel project are that it broadens the students' knowledge in the "green" area and it may help future job hunting.

It should be noted that prior to the announcement of the course project, a quick survey was conducted by the instructor through a show of hands to understand students' familiarity with renewable energy technologies. All 31 students who were present in that day's class had "some" knowledge of the solar and wind energy technologies, while only 4 students had "heard of" cellulosic biofuel technology. The course-end survey in Figure 6 clearly shows that the biofuel project has enhanced students understanding of the manufacturing processes of this specific form of renewable energy.

Figure 7 confirms students' interests in including more renewable energy technologies in the DOE course project. As for which renewable energy technologies should be included in the course project, Figure 8 shows most students would choose wind or solar energy. This can be explained by the fact that renewable energy technologies such as biofuel and geothermal energy are still under development. They are not yet widely demonstrated as wind or solar energy, and currently they have limited commercialization. However, many of these technologies are on the horizon and may have potentials comparable to the relatively mature renewable energy technologies, given sufficient attention in research, development, and demonstration. Since the success of the ISE graduates in job markets is due largely to their wide and rapidly evolving knowledge base, a diversified combination of various renewable energy technologies may benefit their future careers.

Figures 9 and 10 show the students' responses to the questions regarding the ABET outcomes A (application of knowledge of mathematics, science and engineering), E (identify, formulate, and solve engineering problems), and K (use of techniques, skills, and modern engineering tools necessary for engineering practice). Students' self-evaluation and the project reports have shown evidence that these outcomes have been achieved.

The last question in the questionnaire is "What other suggestions do you have regarding the inclusion of renewable energy technologies in the Design of Experiments course?" One of the students has commented, "Including green energy topics into engineering courses could really maintain students' interests and will also allow them to directly see how applicable courses can be to real world applications. Any course with projects like the one we did in DOE allows students to answer the question they always ask. That question is, *How does this apply to the industry?* This biofuel project was an answer to that question." Another representative comment from a different student is "I feel that in this course project, I was focusing a lot on the data and the analysis of it. It definitely helped me out in understanding how to use Minitab and what data you look at to make your assumptions. However I feel that I did not learn as much about the whole process of biofuel manufacturing, as the data had already been collected and given to me, which limited my ability to fully understand what the whole process of biofuel manufacturing really was. If there was a way that we could see how the experiment was actually performed (how the energy consumption was measured based off of changing the factors), then that would be really interesting too." These comments really encourage us and will help us further develop the course and improve the teaching method in the future.

5. Conclusions and Future Work

This paper presents a recent trial of including renewable energy topics in the traditional DOE course for the ISE students. Unlike the previous attempts in this area, the authors choose the under-development cellulosic biofuel manufacturing topic instead of the well-commercialized wind or solar energy in the course project. Students' project reports and the course-end survey have shown that our goal, fostering interests in renewable energy technologies through the application of DOE methods, has been achieved. The authors plan to further develop the course by including more renewable energy technologies as course project topics. The existing cellulosic biofuel project will be revised to include experiments data of more processes. The authors also plan to involve students in the data collection process so that they may gain more hands-on experiences on the complete cycle of design, experiments, analysis, and application.

Acknowledgment

This work was conducted under the financial support from the U.S. National Science Foundation (NSF Grant 1131537).

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